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STANDARDIZED CATCH RATES FOR YELLOWFIN TUNA (*Thunnus albacares*) IN THE 1992-1999 GULF OF MEXICO LONGLINE FISHERY BASED UPON OBSERVER PROGRAMS FROM MEXICO AND THE UNITED STATES

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SUMMARY

*Abundance indices for yellowfin tuna (*Thunnus albacares*) in the Gulf of Mexico for the period 1992-1999 were estimated using data obtained through pelagic longline observer programs conducted by Mexico and the United States. Individual longline set catch per unit effort data, collected by scientific observers, were analyzed to assess effects of environmental factors such as sea surface temperature and depth, time-area factors, and fishery factors such as bait and fleet. Standardized catch rates were estimated through generalized linear models by applying a Poisson error distribution assumption. A stepwise approach was used to quantify the relative importance of the main factors explaining the variance in catch rates. Sea surface temperature, year, area fished, time of set start, and quarter were the factors included in the final model. This cooperative study was conducted under the auspices of the MexUS-Gulf Program.*

RÉSUMÉ

Les indices d'abondance de l'albacore (Thunnus albacares) *pêché dans le golfe du Mexique pendant la période 1992-1999 ont été estimés d'après les données obtenues grâce aux programmes d'observateurs à bord de palangriers menés par le Mexique et les Etats-Unis. Les données de capture par unité d'effort correspondant à des mouillages individuels de palangres rassemblées par les observateurs scientifiques ont été analysées pour évaluer les effets de facteurs environnementaux tels que la température de surface et la profondeur, les facteurs spatio-temporels, et les facteurs de la pêche comme l'appât vivant et la flottille. Le taux standardisé de capture a été estimé par le modèle linéaire généralisé en postulant une distribution Poisson de l'erreur. Une approche par étapes a été utilisée pour quantifier l'importance relative des principaux facteurs qui expliquent la variance du taux de capture. Le modèle définitif comprenant les facteurs suivants: température de surface, année, zone de pêche, heure à laquelle commence le mouillage des lignes, et trimestre. Cette étude en coopération a été menée sous les auspices du programme MexUS-Gulf.*

RESUMEN

*Se estimaron los índices de abundancia para el rabil (*Thunnus albacares*) en el Golfo de México para el periodo 1992-1999, utilizando datos obtenidos mediante los programas de observadores de palangre pelágico llevados a cabo por México y Estados Unidos. Los datos de captura por unidad de esfuerzo de cada lance individual de palangre, recopilados por observadores científicos, fueron analizados para evaluar los efectos de factores medioambientales como la temperatura de la superficie del mar, profundidad, factores espacio-temporales, y de factores de la pesquería como el cebo y la flota. Las tasas de captura estandarizadas se estimaron mediante modelos lineales generalizados aplicando un supuesto de distribución de error Poisson. Se utilizó un enfoque paso a paso para cuantificar la importancia relativa de los principales factores que explican la varianza en las tasas de captura. En el modelo final se incluyeron los siguientes factores: temperatura de la superficie del mar, zona de pesca,*

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hora de inicio del lance, y trimestre. Este estudio conjunto fue llevado a cabo bajo los auspicios del Programa MexUS-Gulf.

KEYWORDS

Abundance indices, Catch/effort, Catch composition, Catch rate standardization, Environmental factors, Long lining, Pelagic fisheries, Surface temperature, Time series analysis, Tuna fisheries

1. INTRODUCTION

The yellowfin tuna fishery in the Gulf of Mexico was started in 1963 by the Japanese longline fleet, which operated until 1980. Longline fleets from Mexico and the U. S. joined the fishery in the early 1980's and presently exploit pelagic resources in the Gulf of Mexico.

The U. S. and Mexico independently developed scientific observer programs and similar databases starting in the early 90's. Several aspects of the longline fisheries in the Gulf of Mexico and the observer programs from both countries have been described by González Ania *et al.* (1998). The present cooperative project is conducted under the auspices of the MexUS-Gulf Program in response to a common interest from both Mexico and the U.S. in improving stock assessments and scientific databases for the sustainable exploitation of pelagic resources in the Gulf of Mexico.

1.1 Evolution of the catch

Longline fisheries in the Gulf of Mexico have experienced high variability in yellowfin tuna catches during the last 35 years (Fig. 1). Catches by the Japanese fleet were very variable between 1963 and 1972, with a minimum of 135 t in 1969 and a maximum of 4,600 t in 1971. Catches became more stable later on, decreasing between 1976 and 1980. During the whole period (1963-1980) Japan had an annual average catch of 1,548 t (31,019 fish).

The U. S. fishery can be divided into two phases. Firstly, an increase in catches since the beginning of operations (1984) up to a historical maximum of 7,500 t (150,581 fish) in 1988, when the U.S. longline fishery consisted of 350-400 vessels (Russell 1992). It is believed that this increase was due in part to the transition towards using live bait (Browder *et al.* 1990). Secondly, catches and number of vessels both decreased, with a slight increase in 1992. Annual average catch (1984-1999) has been 3,138 t.

Three phases can be distinguished in the catch series of the Mexican fishery: first, an increase to 772 t (18,825 fish), caught by 16 vessels, followed by a decrease till the ceasing of operations in 1988. Annual average catch (1982-1987) was 437 t. During this first period Japanese-style longlines and dead bait were used in the fishery. The fleet was heterogeneous in terms of vessel dimensions and fishing power. The second period (1989-1991) was characterized by low yield, with an annual average catch of 71 t. The fleet has been homogeneous since then, using American-style monofilament longline gear, often with live bait. The most recent period is characterized by an increasing trend in catches with an annual average (1992-1999) of 942 t.

1.2 Catch composition

The pelagic longline used by the Mexican fleet is a selective gear, with yellowfin tuna making up over 50% of the catches. Incidental bycatch consists of a variety of pelagic predatory fishes in variable proportions. In 1997, catches were made up by yellowfin tuna (56.3%), bluefin tuna (0.1%), bigeye tuna (0.1%), billfishes (9.0%), sharks (3.2%), and other fishes (31.3%; Table 1).

1.3 Nominal catch rate

Nominal catch rate of yellowfin tuna, expressed as the average number of fish caught by 100 hooks (nominal CPUE), varies by season, with higher values occurring between May and August, and in November (Fig. 2). The geographical distribution of nominal CPUE also varies owing to mesoscale movements of the resource, which are probably due in turn to trophic and reproductive causes. During spring and summer, intermediate and high values of nominal CPUE are found in the central, southern, and western portions of the Mexican EEZ, where fleet activity concentrates. In fall and winter, the fishing zone extends more to the north and east. During that time, the highest values of nominal CPUE are found off the state of Tamaulipas, to the north of the Yucatan peninsula, and near the center of the Mexican EEZ, but the values are quite lower than those from spring-summer (Fig. 3).

1.4 Catch rate standardization

Catch and effort data are being increasingly used to construct indices of relative abundance for commercial and recreational fisheries (Hoey *et al.* 1996; Brown 1998; Goñi *et al.* 1999). However, nominal catch rates obtained from fishery statistics or observer programs require standardization to correct for the effect of factors not related to regional fish abundance but assumed to affect fish availability and vulnerability (Bigelow *et al.* 1999).

Use of generalized linear models (GLMs) is becoming standard practice in catch rate standardization because this approach allows identification of the factors that influence catch rates and calculation of standardized abundance indices through the year effect (Goñi *et al.* 1999). A variety of error distributions of catch rate data have been assumed in GLM analyses (Lo *et al.* 1992; Bigelow *et al.* 1999; Goñi *et al.* 1999; Punt *et al.* 1999). Brown (1998) used a two-step GLM analysis based on a delta-lognormal model proposed by Lo *et al.* (1992) to model the proportion of trips that caught yellowfin tuna (*Thunnus albacares*) or bigeye tuna (*Thunnus obesus*) and the catch per trip for the positive trips only in the Virginia-Massachusetts rod and reel fishery. In the present study we model standardized indices of relative abundance of yellowfin tuna assuming that the errors in the dependent variable follow a Poisson distribution.

2. MATERIAL AND METHODS

Under Mexico's fisheries regulations, vessels fishing longline gear have observers on board during all fishing trips. The objective of the United States' observer program is to achieve a representative, 5% sampling level of the fishing effort in the Gulf of Mexico and other fishing areas during each calendar quarter of the year. Observers of both programs record detailed, set-specific data needed to describe the catch and effort of the longline fishery.

A combined data set was created which included the variables common to both observer programs (Table 2). For this analysis, data were available from the Mexican observer program for the period 1993-1997 and from the United States' observer program, for the period 1992-1999. After an initial exploratory analysis, factors which were considered as possible influences on catch rates included environmental factors such as mean sea surface temperature (MEANTEMP) and depth (SEADEPTH), time-area factors such as YEAR, QUARTER, fishing area (ZONE) and two measures of the time of day during which a set was initiated (SETSTART, 2AM-11AM or 11AM-2AM as well as DAYNIGHT, day or night starts), and fishery factors such as bait category (BAITCAT, fish or cephalopod), bait status (BAITLD, live or dead) and FLEET (Mexico or United States). Mean sea surface temperature (MEANTEMP) was calculated for each set as the average of temperature data measured *in situ* at the beginning and end of gear setting for the U. S. fleet, and at the beginning and end of both gear setting and retrieval in the case of the Mexican fleet. Five fishing areas (ZONE) were defined based upon the latitude and longitude of the sets (Fig. 4).

Standardized indices were developed using generalized linear models. Catch rates were modeled as a function of the various factors. A Poisson regression was fitted to the number of yellowfin tuna per set (log link) and the natural log of the mean operating time for the set (in hours) was used as the offset term. The mean operating time of each set is intended to reflect the average time that each hook was in the water. It was calculated by dividing the total time to set out and to retrieve the gear by two, then adding the soak time during which the gear is left undisturbed.

A forward stepwise approach was used to quantify the relative importance of the main factors explaining the variance in catch rates. First, a null model was run with no factors entered into the model. Results from the null model reflect the distribution of the nominal data. Each potential factor was then tested one at a time. The results were then ranked from greatest to least reduction in deviance per degree of freedom when compared to the null model. The factor which resulted in the greatest reduction in deviance per degree of freedom was then incorporated into the model, provided two conditions were met: 1) the effect of the factor was determined to be significant at least at the 5% level based on a Chi-Square test, and 2) the deviance per degree of freedom was reduced by at least 1% from the less complex model. This process was repeated, adding factors one at a time at each step, until no factor met the criteria for incorporation into the final model. All models in the stepwise approach were fitted with the SAS GENMOD procedure, whereas the final model was run with the SAS MIXED procedure (SAS Inst. Inc.). The relative indices of abundance by year were determined based upon the standardized year effects.

3. RESULTS AND DISCUSSION

The stepwise construction of the model is shown in Table 3. The final model included the factors MEANTEMP, YEAR, ZONE, SETSTART and QUARTER, ranked by decreasing importance. The results of the relative abundance analyses for yellowfin tuna in the Gulf of Mexico (1992-1999) are shown in Table 4. Table 5 and Figure 5 show the final model and relative index trend.

Spatial-temporal heterogeneity in the marine environment is believed to greatly affect the biology, dynamics, and availability of tuna stocks, as well as their vulnerability to fishing gear, thus introducing a source of variability in nominal catch rates. Sea surface temperature is one of the most important physical factors because it modifies the geographical and vertical aggregation patterns of tuna, through its effect on feeding, reproductive, and migratory behavior and body thermoregulation (Fonteneau 1998). Acoustic telemetry studies of the microscale movement patterns of yellowfin tuna conducted since 1982 have demonstrated that this species occurs in the warm-water mixed surface layer and the upper part of the thermocline in tropical and subtropical seas, moving occasionally into colder waters below the thermocline, probably to feed or thermoregulate (Block *et al.* 1997, Bard 1998). The consistent occurrence of yellowfin tuna in this layer of homogeneous temperature allows us to assume that sea surface temperatures taken simultaneously to fishing operations, either measured *in situ* from fishing vessels–as in the present study–or from satellites, are representative of the thermal habitat available to this species.

The importance of sea surface temperature as an explanatory variable in the present analysis points to the potential utility of exploring other possible relationships between catch rate and mesoscale oceanic features by including thermal gradients in the model. Detection of a strong relationship between nominal CPUE and temperature was due –at least in part– to the space-time microscale approach used. In that respect, our results differ from those by Power and May (1991), who did not find any perceptible relationship between satellite observations of sea surface temperature and yellowfin tuna nominal CPUE in the longline fishery of the northwestern Gulf of Mexico. The relationship may have been masked by data limitations and uncertainty in the geographical locations of the sets in that study.

It is possible, however, that the relationship found between nominal CPUE and temperature may not only be due to specific temperature preferences by yellowfin tuna, especially because over 99% of the sets analyzed occurred in waters with surface temperatures above 21º C, considered to be the thermal minimum for the distribution of this species (Fonteneau 1998). Variability in nominal catch rates can also be related to other physical, chemical, and biological processes or factors in the ocean (e.g. water transparency, circulation patterns, frontal zones, salinity, plankton, nekton), which together with temperature define the identity, structure, and interaction of water masses and can affect the availability of potential prey and the capture efficiency of tuna (Laurs *et al.* 1984, Bigelow *et al.* 1999).

The significant effect of time of set start (SETSTART) on catch rate may be related to predatory behavior. Yellowfin tuna tracked by acoustic telemetry have displayed a behavioral pattern in which they rapidly ascend to the surface at dawn; a similar behavior has been observed in the bluefin tuna (Block *et al.* 1997). This behavioral pattern may likely increase the vulnerability of yellowfin tuna to fishing gear.

The present study represents the first cooperative attempt to merge fishery and environmental information from the complete distribution range of the yellowfin tuna in the Gulf of Mexico, estimate the best available relative abundance indices, and model recent trends in CPUE. The current analysis did not consider terms representing interactions between factors in the model. It is possible that such interaction terms might contribute substantially to a final model. Results may also be improved by adding other predictor variables to the model, extending the time series, and taking into account the size-age structure and sex of the catches. Variable transformation and use of generalized additive models (GAMs) may also increase the explanatory power of the model, due to the likely nonlinearity of many of the functional relationships between catch rate and the predictor variables.

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Table 1. Catch composition of the Mexican longline fleet in the Gulf of Mexico, Mar-Dec 1997.

NAME		DISPOSITION			
COMMON	SCIENTIFIC	% Retained	% Released Alive	% Discarded Dead	Proportion of the total catch (% by number)
TOTAL CATCH		**73.30**	**6.51**	**20.19**	**100.00**
TARGET SPECIES					
YELLOWFIN TUNA	*Thunnus albacares*	**90.22**	**4.62**	**5.16**	**56.37**
INCIDENTAL CATCH		**51.44**	**8.95**	**39.61**	**43.63**
OTHER TUNAS		**88.53**	**5.44**	**6.03**	**8.67**
Blackfin Tuna	*Thunnus atlanticus*	91.42	6.08	2.50	6.57
Skipjack Tuna	*Katsuwonus pelamis*	79.89	0.56	19.55	1.83
Bluefin Tuna	*Thunnus thynnus thynnus*	61.54	38.46	0.00	0.13
Bigeye Tuna	*Thunnus obesus*	92.31	7.69	0.00	0.13
BILLFISHES		**83.44**	**11.65**	**4.91**	**9.59**
Sailfish	*Istiophorus albicans*	80.57	11.48	7.95	4.64
Swordfish	*Xiphias gladius*	91.86	5.23	2.91	1.76
White Marlin	*Tetrapturus albidus*	86.17	13.83	0.00	0.96
Blue Marlin	*Makaira nigricans*	78.89	20.00	1.11	0.92
Longbill Spearfish	*Tetrapturus pfluegeri*	90.48	7.94	1.59	0.65
Unidentified Marlin		80.33	18.03	1.64	0.63
Unidentified Billfishes		0.00	33.33	66.67	0.03
SHARKS		**81.85**	**14.97**	**3.18**	**3.22**
Silky & Blacktip Sharks	*Carcharhinus falciformis, C. brevipinna, C. limbatus*	97.78	2.22	0.00	0.92
Mako Sharks	*Isurus paucus, I. oxirinchus*	81.82	9.09	9.09	0.34
Bull Shark	*Carcharhinus leucas*	93.10	6.90	0.00	0.30
Whitetip Shark	*Carcharhinus longimanus*	14.29	85.71	0.00	0.22
Thresher Sharks	*Alopias vulpinus, A. superciliosus*	73.68	15.79	10.53	0.19
Tiger Shark	*Galeocerdo cuvier*	66.67	22.22	11.11	0.18
Hammerhead Sharks	*Sphyrna lewini, S. mokarran*	100.00	0.00	0.00	0.07
Unidentified Sharks		81.44	15.46	3.09	0.99
OTHER FISHES		**18.65**	**8.28**	**73.07**	**22.15**
Lancetfishes	*Alepisaurus ferox, A. brevirostris*	0.24	4.20	95.56	12.93
Escolar	*Lepidocybium flavobrunneum*	0.48	20.58	78.93	4.23
Wahoo	*Acanthocybium solandri*	91.35	0.96	7.69	2.13
Dolphinfishes	*Coryphaena hippurus, C. equiselis*	89.29	2.98	7.74	1.72
Jacks	(Family Carangidae)	97.37	2.63	0.00	0.39
Mantas	*Manta spp., Mobula spp.*	0.00	95.45	4.55	0.23
Puffers	(Family Tetraodontidae)	0.00	60.00	40.00	0.10
Little Tuna & Bonito	*Euthynnus alletteratus & Sarda sarda*	100.00	0.00	0.00	0.07
Barracuda	*Sphyraena barracuda*	100.00	0.00	0.00	0.06
Molas (sunfishes)	*Mola mola, M. lanceolata, Ranzania spp.*	0.00	75.00	25.00	0.04
Pomfrets	(Family Bramidae)	0.00	0.00	100.00	0.02
Unidentified Fishes		38.10	14.29	47.62	0.22

Table 2. General statistics of the Gulf of Mexico tuna data base.

MexUS-Golfo	1992	1993	1994	1995	1996	1997	1998	1999	TOTAL
Observed trips	8	85	191	303	143	58	12	22	822
Sets	48	434	996	1668	892	393	58	143	4,632
YFT sampled	495	6246	21222	29102	9595	5953	578	1460	74,651
YFT caught	607	7430	22414	31566	11453	6522	686	1585	82,263
% SAMPLED	**81.55%**	**84.06%**	**94.68%**	**92.19%**	**83.78%**	**91.28%**	**84.26%**	**92.11%**	**90.75%**

Table 3. Results of the stepwise procedure to develop the catch rate model.

FACTOR	df	deviance	deviance/df	%diff.	delta%	L	ChiSquare	Pr>Chi
NULL	3693	53920.542	14.6007			125048.9	.	.
MEANTEMP	3692	47758.179	12.9356	11.404	11.404	128130.1	6162.3633	< 0.00001
YEAR	3686	48723.445	13.2185	9.467		127647.5	5197.0973	< 0.00001
QUARTER	3690	49532.761	13.4235	8.063		127242.8	4387.7814	0.00000
ZONE	3689	50475.697	13.6828	6.287		126771.4	3444.8457	0.00000
SETSTART	3692	50987.275	13.8102	5.414		126515.6	2933.2673	0.00000
BAITCAT	3692	51179.637	13.8623	5.057		126419.4	2740.9057	0.00000
BAITLD	3692	51180.656	13.8626	5.055		126418.9	2739.8866	0.00000
FLEET	3692	51539.829	13.9599	4.389		126239.3	2380.7136	0.00000
SEADEPTH	3691	53300.462	14.4407	1.096		125359.0	587.7077	0.00000
DAYNIGHT	3692	53877.013	14.5929	0.053		125070.7	43.5296	0.00000
MEANTEMP+								
YEAR	3685	44540.985	12.0871	17.216	5.811	129738.7	3217.1945	< 0.00001
ZONE	3688	45540.617	12.3483	15.427		129238.9	2217.5621	< 0.00001
SETSTART	3691	45814.066	12.4124	14.988		129102.2	1944.1127	< 0.00001
FLEET	3691	46307.378	12.546	14.073		128855.5	1450.8006	< 0.00001
BAITLD	3691	46719.793	12.6578	13.307		128649.3	1038.3865	< 0.00001
QUARTER	3689	46941.749	12.7248	12.848		128538.3	816.4299	< 0.00001
BAITCAT	3691	47066.894	12.7518	12.663		128475.8	691.2854	< 0.00001
SEADEPTH	3690	47631.791	12.9083	11.591		128193.3	102.7111	< 0.00001
DAYNIGHT	3691	47651.132	12.9101	11.579		128183.6	107.0472	< 0.00001
MEANTEMP+YEAR+								
ZONE	3681	42621.813	11.5789	20.696	3.481	130698.3	1919.1711	< 0.00001
SETSTART	3684	42892.195	11.6428	20.259		130563.1	1648.7891	< 0.00001
QUARTER	3682	43325.894	11.7669	19.409		130346.2	1215.091	< 0.00001
FLEET	3684	43391.954	11.7785	19.329		130313.2	1149.0309	< 0.00001
BAITLD	3684	44017.1	11.9482	18.167		130000.6	523.8847	< 0.00001
BAITCAT	3684	44179.488	11.9923	17.865		129919.4	361.4961	< 0.00001
SEADEPTH	3683	44435.705	12.0651	17.366		129791.3	81.4531	< 0.00001
DAYNIGHT	3684	44467.338	12.0704	17.330		129775.5	73.6467	< 0.00001
MEANTEMP+YEAR+ZONE+								
SETSTART	3680	41449.157	11.2634	22.857	2.161	131284.6	1172.6562	< 0.00001
QUARTER	3678	41776.881	11.3586	22.205		131120.8	844.9324	< 0.00001
BAITCAT	3680	42472.373	11.5414	20.953		130773.0	149.4402	< 0.00001
BAITLD	3680	42556.074	11.5642	20.797		130731.2	65.7392	< 0.0001
DAYNIGHT	3680	42562.915	11.566	20.785		130727.7	58.8988	< 0.0001
FLEET	3680	42580.445	11.5708	20.752		130719.0	41.3679	< 0.0001
SEADEPTH	3679	42586.997	11.5757	20.718		130715.7	16.8916	0.00004
MEANTEMP+YEAR+ZONE+SETSTART								
QUARTER	3677	40507.534	11.0165	24.548	1.691	131755.4	941.6237	< 0.00001
BAITLD	3679	41381.604	11.2481	22.962		131318.4	67.553	< 0.00001
BAITCAT	3679	41387.395	11.2496	22.952		131315.5	61.7625	< 0.00001
SEADEPTH	3678	41414.666	11.2601	22.880		131301.9	19.3138	0.00001
FLEET	3679	41429.053	11.261	22.874		131294.7	20.1043	0.00001
DAYNIGHT	3679	41446.512	11.2657	22.841		131285.9	2.6454	0.10385
MEANTEMP+YEAR+ZONE+SETSTART+QUARTER								
SEADEPTH	3675	40444.387	11.0053	24.625	0.077	131787.0	49.9764	< 0.00001
BAITLD	3676	40462.701	11.0073	24.611		131777.8	44.8321	< 0.00001
BAITCAT	3676	40491.383	11.0151	24.558		131763.5	16.1508	0.00006
FLEET	3676	40493.312	11.0156	24.554		131762.5	14.2218	0.00016
DAYNIGHT	3676	40496.084	11.0163	24.550		131761.2	11.4495	0.00072

FINAL MODEL: MEANTEMP+YEAR+ZONE+SETSTART+QUARTER

% diff: percent difference in deviance/df between each factor and the null model**;** delta%: percent difference in deviance/df between the newly included factor and the previous factor entered into the model; L: log likelihood; ChiSquare: Pearson Chi-square statistic; Pr>Chi: significance level of the Chi-square statistic.

Table 4. Results of final model fit.

Class	Levels	Values
YEAR	8	1992 1993 1994 1995 1996 1997 1998 1999
ZONE	5	1 2 3 4 5
SETSTART	2	11AM-2AM 2AM-11AM
QUARTER	4	1 2 3 4

Parameter Search

COVP1	Variance	RLL	-2RLL	Objective
12.7421	12.7421	-4854.57	9709.146	2951.2725

Covariance Parameter Estimates (REML)

Cov Parm	Estimate
Residual	12.74206900

Model Fitting Information for _Z
Weighted by _W

Description	Value
Observations	3694.000
Res Log Likelihood	-4854.57
Akaike's Information Criterion	-4855.57
Schwarz's Bayesian Criterion	-4858.68
-2 Res Log Likelihood	9709.146
Deviance	40507.5335
Scaled Deviance	3179.0389
Pearson Chi-Square	46852.5877
Scaled Pearson Chi-Square	3677.0000
Extra-Dispersion Scale	12.7421

Solution for Fixed Effects

Effect	YEAR	ZONE	SETSTART	QUARTER	Estimate	Std Error	DF	t	Pr > |t|	Alpha	Lower	Upper
INTERCEPT					-6.92959226	0.27092023	3677	-25.58	0.0001	0.05	-7.4608	-6.3984
MEANTEMP					0.09521548	0.00895859	3677	10.63	0.0001	0.05	0.0777	0.1128
YEAR	1992				0.55951025	0.19062930	3677	2.94	0.0034	0.05	0.1858	0.9333
YEAR	1993				0.09926318	0.12217103	3677	0.81	0.4166	0.05	-0.1403	0.3388
YEAR	1994				0.41698643	0.11170266	3677	3.73	0.0002	0.05	0.1980	0.6360
YEAR	1995				-0.01358550	0.11156263	3677	-0.12	0.9031	0.05	-0.2323	0.2051
YEAR	1996				-0.25025839	0.11522004	3677	-2.17	0.0299	0.05	-0.4762	-0.0244
YEAR	1997				0.02399061	0.11628798	3677	0.21	0.8366	0.05	-0.2040	0.2520
YEAR	1998				0.05499820	0.17087855	3677	0.32	0.7476	0.05	-0.2800	0.3900
YEAR	1999				0.00000000	.	.	.	.	.	.	.
ZONE		1			0.50959821	0.08103614	3677	6.29	0.0001	0.05	0.3507	0.6685
ZONE		2			0.35531423	0.08390694	3677	4.23	0.0001	0.05	0.1908	0.5198
ZONE		3			0.14469112	0.08380501	3677	1.73	0.0843	0.05	-0.0196	0.3090
ZONE		4			0.05625017	0.15225010	3677	0.37	0.7118	0.05	-0.2423	0.3548
ZONE		5			0.00000000	.	.	.	.	.	.	.
SETSTART			11AM-2AM		-0.35317347	0.03649981	3677	-9.68	0.0001	0.05	-0.4247	-0.2816
SETSTART			2AM-11AM		0.00000000	.	.	.	.	.	.	.
QUARTER				1	0.04305494	0.06086736	3677	0.71	0.4794	0.05	-0.0763	0.1624
QUARTER				2	0.26125155	0.04217407	3677	6.19	0.0001	0.05	0.1786	0.3439
QUARTER				3	-0.00646172	0.04890607	3677	-0.13	0.8949	0.05	-0.1023	0.0894
QUARTER				4	0.00000000	.	.	.	.	.	.	.

Tests of Fixed Effects

Source	NDF	DDF	Type III ChiSq	Type III F	Pr > ChiSq	Pr > F
MEANTEMP	1	3677	112.96	112.96	0.0001	0.0001
YEAR	7	3677	259.87	37.12	0.0001	0.0001
ZONE	4	3677	77.74	19.44	0.0001	0.0001
SETSTART	1	3677	93.63	93.63	0.0001	0.0001
QUARTER	3	3677	74.92	24.97	0.0001	0.0001

Table 4. Results of final model fit (cont.)

Parameter Estimates

Effect	YEAR	ZONE	SETSTART	QUARTER	Estimate	Std Error	DF	t	Pr > |t|	Alpha	Lower	Upper
INTERCEPT					-6.9296	0.2709	3677	-25.58	0.0001	0.05	-7.4608	-6.3984
MEANTEMP					0.0952	0.0090	3677	10.63	0.0001	0.05	0.0777	0.1128
YEAR	1992				0.5595	0.1906	3677	2.94	0.0034	0.05	0.1858	0.9333
YEAR	1993				0.0993	0.1222	3677	0.81	0.4166	0.05	-0.1403	0.3388
YEAR	1994				0.4170	0.1117	3677	3.73	0.0002	0.05	0.1980	0.6360
YEAR	1995				-0.0136	0.1116	3677	-0.12	0.9031	0.05	-0.2323	0.2051
YEAR	1996				-0.2503	0.1152	3677	-2.17	0.0299	0.05	-0.4762	-0.0244
YEAR	1997				0.0240	0.1163	3677	0.21	0.8366	0.05	-0.2040	0.2520
YEAR	1998				0.0550	0.1709	3677	0.32	0.7476	0.05	-0.2800	0.3900
YEAR	1999				0.0000	.	.	.	.	.	.	.
ZONE		1			0.5096	0.0810	3677	6.29	0.0001	0.05	0.3507	0.6685
ZONE		2			0.3553	0.0839	3677	4.23	0.0001	0.05	0.1908	0.5198
ZONE		3			0.1447	0.0838	3677	1.73	0.0843	0.05	-0.0196	0.3090
ZONE		4			0.0563	0.1523	3677	0.37	0.7118	0.05	-0.2423	0.3548
ZONE		5			0.0000	.	.	.	.	.	.	.
SETSTART			11AM-2AM		-0.3532	0.0365	3677	-9.68	0.0001	0.05	-0.4247	-0.2816
SETSTART			2AM-11AM		0.0000	.	.	.	.	.	.	.
QUARTER				1	0.0431	0.0609	3677	0.71	0.4794	0.05	-0.0763	0.1624
QUARTER				2	0.2613	0.0422	3677	6.19	0.0001	0.05	0.1786	0.3439
QUARTER				3	-0.0065	0.0489	3677	-0.13	0.8949	0.05	-0.1023	0.0894
QUARTER				4	0.0000	.	.	.	.	.	.	.

Least Squares Means

Effect	YEAR	LSMEAN	Std Error	DF	t	Pr > |t|	Alpha	Lower	Upper	STDERETA	Mu	DMU	STDERMU	LowerMu	UpperMu
YEAR	1992	-3.7105	0.1700	3677	-21.82	0.0001	0.1	-3.9902	-3.4307	0.17005	0.0245	0.024466	.0041604	0.0185	0.0324
YEAR	1993	-4.1707	0.0774	3677	-53.92	0.0001	0.1	-4.2980	-4.0435	0.07735	0.0154	0.015441	.0011944	0.0136	0.0175
YEAR	1994	-3.8530	0.0415	3677	-92.77	0.0001	0.1	-3.9213	-3.7847	0.04153	0.0212	0.021216	.0008812	0.0198	0.0227
YEAR	1995	-4.2836	0.0401	3677	-106.9	0.0001	0.1	-4.3495	-4.2176	0.04007	0.0138	0.013793	.0005527	0.0129	0.0147
YEAR	1996	-4.5202	0.0479	3677	-94.42	0.0001	0.1	-4.5990	-4.4415	0.04787	0.0109	0.010886	.0005212	0.0101	0.0118
YEAR	1997	-4.2460	0.0559	3677	-76.02	0.0001	0.1	-4.3379	-4.1541	0.05585	0.0143	0.014322	.0007999	0.0131	0.0157
YEAR	1998	-4.2150	0.1442	3677	-29.23	0.0001	0.1	-4.4522	-3.9778	0.14419	0.0148	0.014773	.0021301	0.0117	0.0187
YEAR	1999	-4.2700	0.1058	3677	-40.36	0.0001	0.1	-4.4441	-4.0959	0.10581	0.0140	0.013982	.0014794	0.0117	0.0166

Table 5. Relative Abundance Indices for yellowfin tuna.

YEAR	INDEX	LCI*	UCI*	CV
1992	1.519	1.148	2.009	0.170
1993	0.958	0.844	1.089	0.077
1994	1.317	1.230	1.410	0.042
1995	0.856	0.802	0.915	0.040
1996	0.676	0.625	0.731	0.048
1997	0.889	0.811	0.975	0.056
1998	0.917	0.723	1.162	0.144
1999	0.868	0.729	1.033	0.106

*Approximate 95% lower and upper confidence intervals.

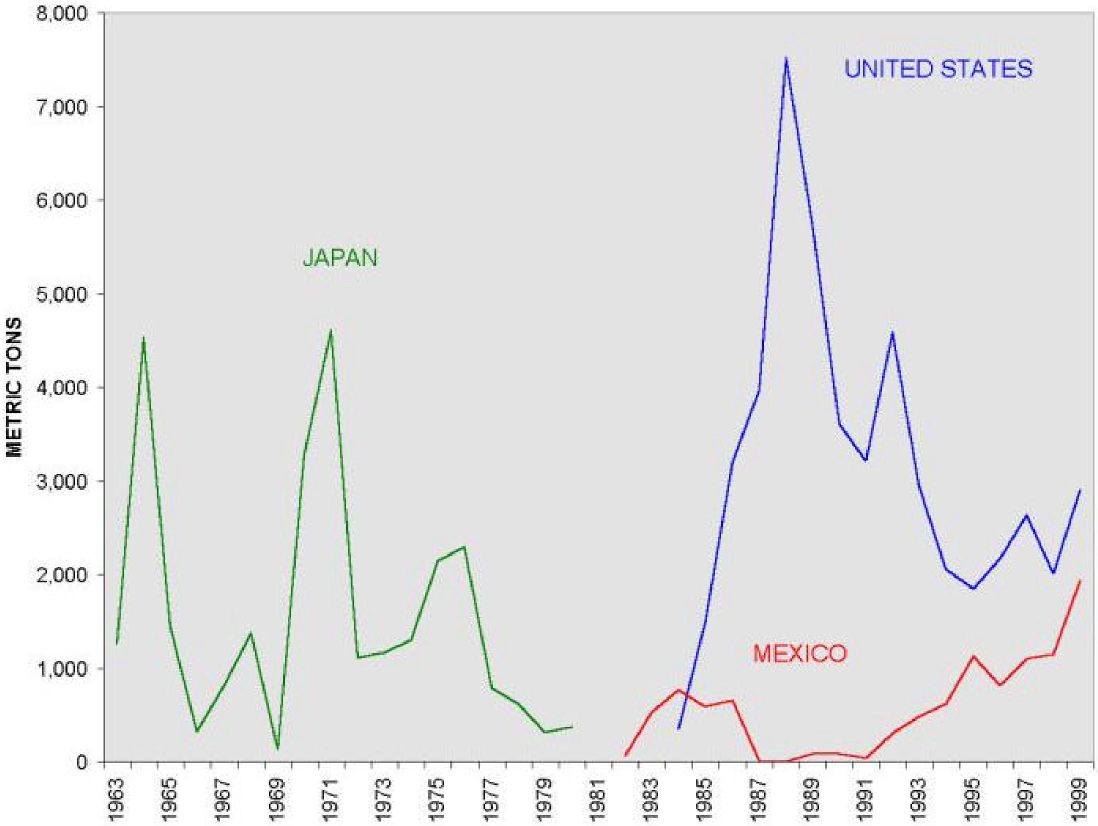

Figure 1. Yellowfin tuna catches in the Gulf of Mexico.

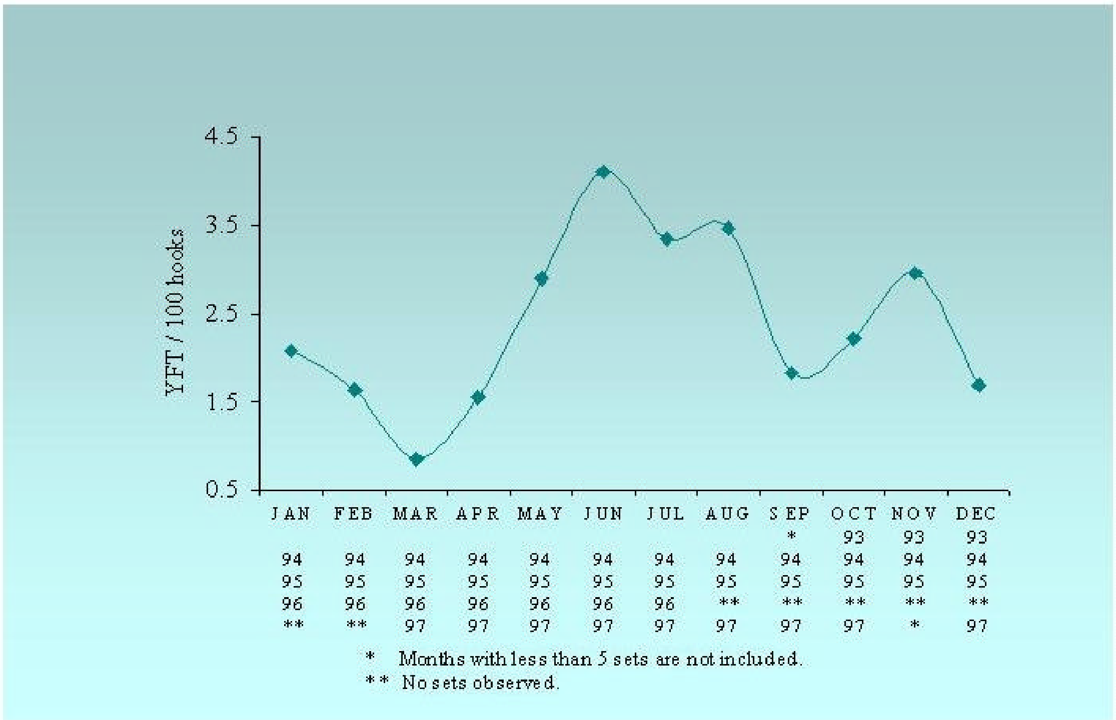

Figure 2. Seasonal variability of the nominal catch rate of yellowfin tuna. Years used for each monthly average are indicated. Mexican longline fleet, 1993-1997.

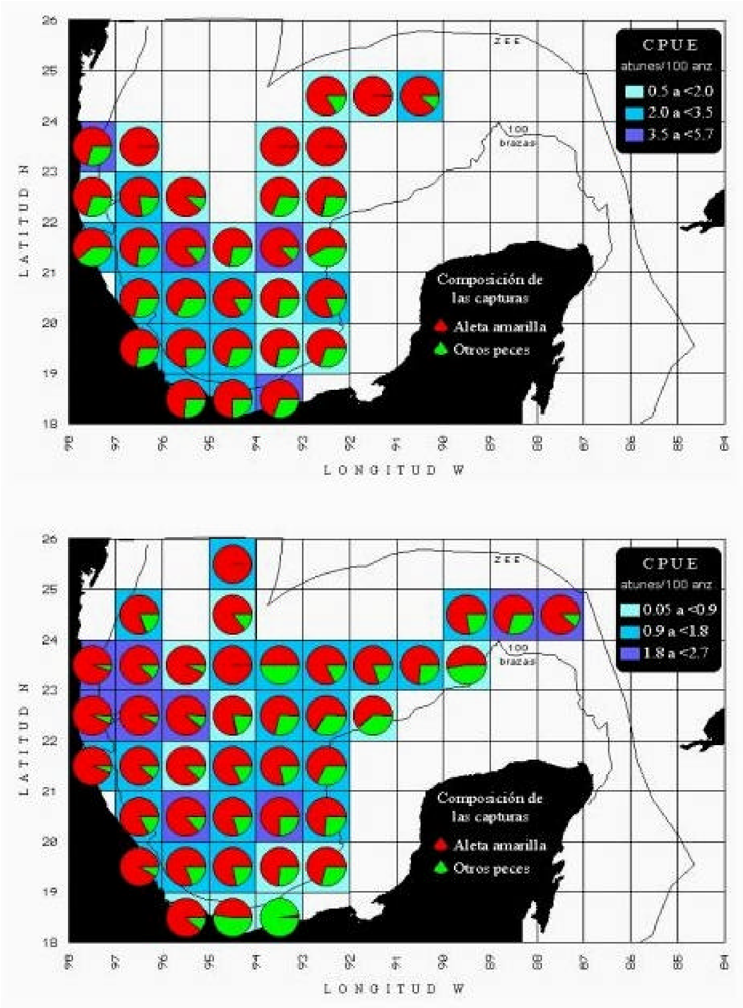

Figure 3. Geographical distribution of nominal CPUE of yellowfin tuna and relative catch composition of the Mexican longline fleet, 1995. Upper panel: spring-summer; lower panel: fall-winter.

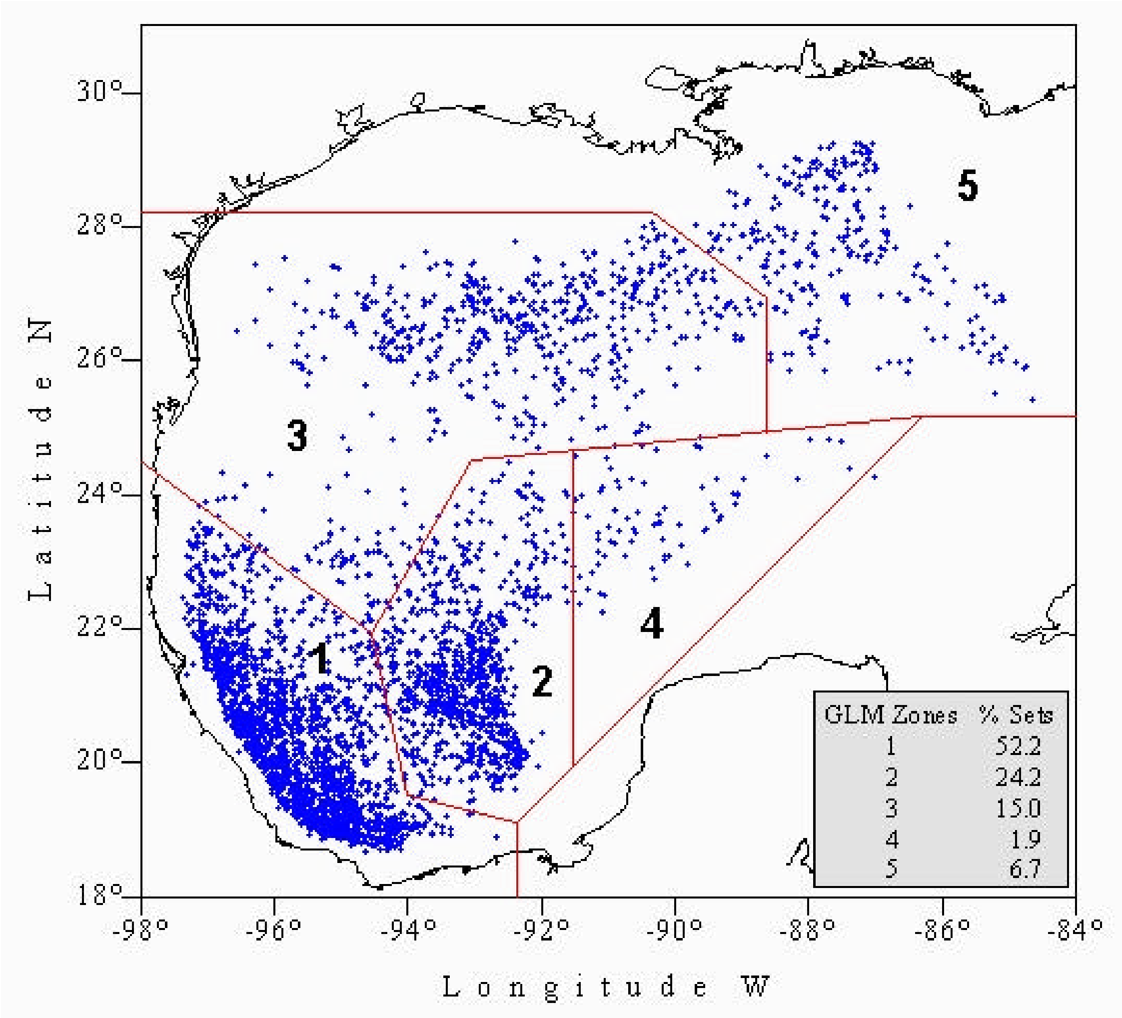

Figure 4. Fishing areas defined for the GLM analyses and distribution of pelagic longline sets sampled by observer programs.

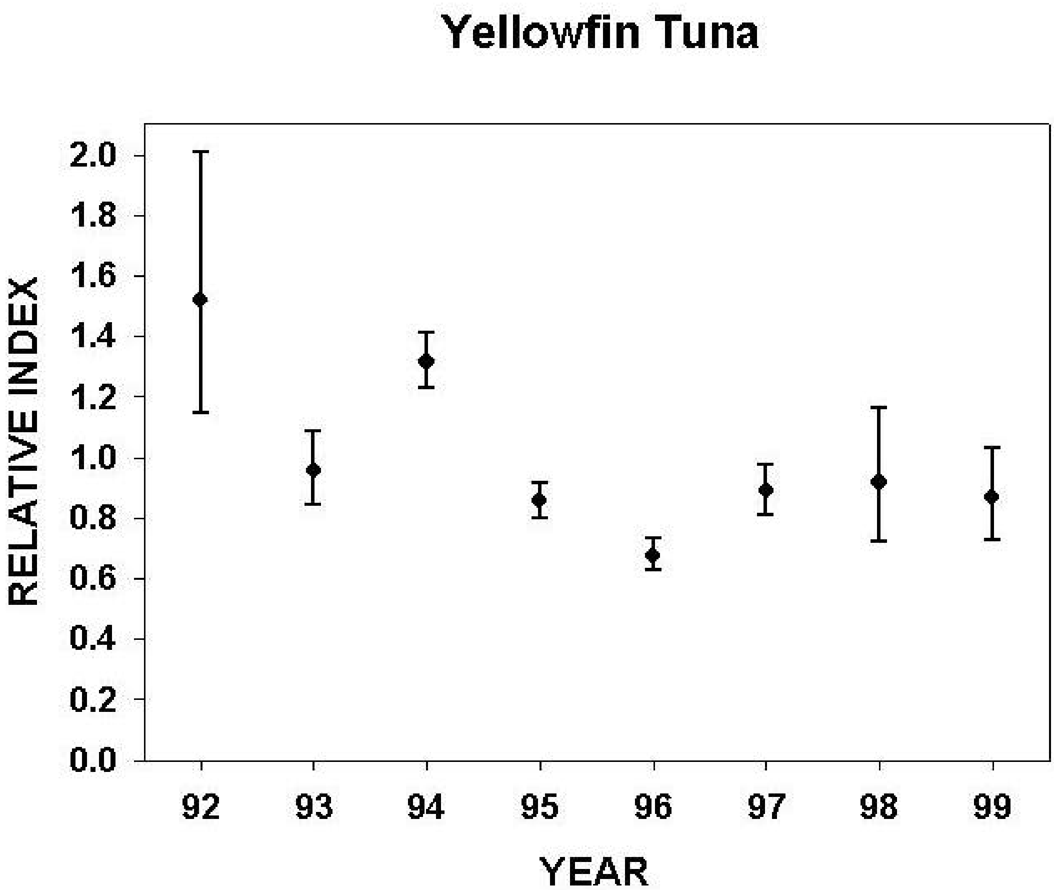

Figure 5. Relative abundance indices for yellowfin tuna with approximate 95% confidence intervals. (Yellowfin caught per set, offset: natural log of mean hours each hook is in the water, error distribution: Poisson). Model = MEANTEMP+YEAR+ZONE+SETSTART+QUARTER